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USING A LEARNING PROGRESSION TO INFORM SCIENTIFIC ARGUMENTATION IN TALK AND WRITING

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Abstract

Argumentation is a central goal of science education because it can engage students in a complex scientific practice in which they construct and justify knowledge claims. Yet argumentation rarely occurs in science classrooms. Moreover, although there is a growing body of research around argumentation in science, there has been little focus on developing a learning progression for this practice. In this paper, we describe the learning progression we have developed to understand both students work in the practice of scientific argumentation and the ways in which the instructional environment can support students in that practice. This learning progression describes three dimensions that educators can use to influence the complexity of the students' argumentation: 1) Problem context, 2) Argumentative product, and 3) Argumentative process. This paper illustrates how educators can use these three dimensions to both support and analyze student work in the practice of scientific argumentation.

Introduction

Argumentation is a central goal of science education and can shift the focus of science classrooms from one of rote memorization to engaging students in a complex scientific practice in which they construct and justify knowledge claims (Duschl et al., 2007). Engaging in what Andriessen calls "collaborative argumentation" (2007) is an important part of how students learn: "In argumentation…. Knowledge and opinions can be (re)constructed and co-constructed and expand students' understanding of specific concepts or problems" (Veerman, 2003, p. 118). For example, when exploring students' engagement in scientific argumentation, Hatano and Inagaki (1991) found that the discussions supported students' sensemaking because throughout discussion individual participants move between presenting an understanding, evaluating other understandings, and refining their own understandings in light of that discussion. Similarly, as argued by Ford (2008), scientific argumentation enables students to engage in knowledge construction: If students are not empowered to criticize the ideas being discussed in a culture that values evidence, then they must accept the ideas that sound plausible and/or are held by the individual with the most clout (e.g., the teacher in a whole class discussion or a particular student in small group work). Thus, the practice of argumentation is an important part of knowledge construction in science.

Yet argumentation rarely occurs in science classrooms (Newton, Driver, & Osborne, 1999). Typical classroom practices often inhibit this type of persuasive discourse. For example, in conventional classroom practices, students are rarely in positions to substantively engage with one another's ideas (Hogan & Corey, 2001; Lemke, 1990). Moreover, when students do engage in scientific argumentation in science classrooms, they frequently have difficulty justifying their claims both in talk and in writing. That is, when confronted with data sets, students struggle to select appropriate data to use as evidence (McNeill & Krajcik, 2007) or provide sufficient evidence (Sandoval & Millwood, 2005) in their written explanations. Students also have difficulty providing the backing or reasoning for why they chose their evidence (Bell & Linn, 2000; McNeill, Lizotte, Krajcik, & Marx, 2006). That said, research has demonstrated that students have the skills to engage in preliminary forms of scientific argumentation (Berland & Hammer, 2009; Berland & Reiser, 2009; Louca, Hammer, & Bell, 2002; Radinsky, 2008). Combining these research veins suggests that engaging in scientific argumentation is complex and requires a learning environment designed to elicit student participation in this practice.

Although there is a growing body of research around argumentation in science, there has been little focus on developing a learning progression for this practice (Duschl, Schweingruber, & Shouse, 2007). A learning progression is typically defined as a sequence of successively more complex ways of thinking about a practice or content that develop over time (Smith, Wiser, Anderson, & Krajcik, 2006). In the case of scientific argumentation, the learning progression must account for the complex relationship between the instructional environment and students' work in the practice. In this paper, we describe the learning progression we have developed to understand both students' work in the practice of scientific argumentation and the instructional environment that supports students in that practice. This proposed progression is the culmination of our work supporting scientific argumentation across grades and content areas.

Classroom and Curricular Context

We use four classroom examples to discuss and illustrate our proposed learning progression. We selected these examples because they represent different levels of complexity for the three dimensions of our learning progression. Furthermore, the examples span elementary, middle and high school students, thereby allowing us to discuss potential implications in terms of both the age and experience of the students.

When introducing the three dimensions, we focus on the first example from a 12^{th} grade classroom that enacted an urban ecology curriculum in the spring of 2007. The students attended a public high school in a large urban district in New England. The high school was a school of choice that students either selected or were randomly placed in based on a lottery system. The majority of the students in the high school were African American (62%) and Hispanic (33%) with approximately 79% of the students being eligible for free and reduced lunch. Furthermore, the high school had an approximately 60% high school graduation rate in four years. The teacher, Mr. Dodson, was a white male who had been teaching science for six years at the time of this study. In the lesson on which this example focuses, the students are using Google maps from three areas in their city to

predict the site that has the highest bird biodiversity. Area #1 included mainly tall buildings and little green space. Area #2 was a neighborhood that included four parks. Site #3 was on the outskirts of the city and contained a golf course. Mr. Dodson asked his students to write their responses to the following question: “Comparing the three sites, which site would you expect to have the highest bird biodiversity? Why?” After students recorded their responses, Mr. Dodson then led a class discussion in which he asked the students to debate their answers to the question. In the following sections, we use examples from both their writing and talk to illustrate the three dimensions of our learning progression.

Three Dimensions of the Learning Progression

Educators can influence the complexity of the students’ argumentation through the instructional environment. In order to charaterize that instructional environment, we consider three different dimensions of a learning progression: 1) Problem context, 2) Argumentative product, and 3) Argumentative process. Table 1 provides a summary of the different dimensions and how their complexity can be manipulated.

Table 1: Three Dimensions of the Learning Progression

<table>
<tr><th>Dimension</th><th colspan="6">Simple → Complex</th></tr>
<tr><td rowspan="3">Problem context</td><td colspan="3">Question is closely defined with two-three potential answers</td><td colspan="3">Question is open with multiple potential answers</td></tr>
<tr><td colspan="2">Data set is small</td><td colspan="2">Data set is large</td><td colspan="2">Students define data set</td></tr>
<tr><td colspan="3">Data set is limited to appropriate data</td><td colspan="3">Data set includes both appropriate and inappropriate data</td></tr>
<tr><td rowspan="3">Argumentative product</td><td>Claims are defended</td><td colspan="2">Claims are defended with evidence</td><td colspan="2">Claims are defended with evidence, and reasoning.</td><td>Claims are defended with supporting, appropriate evidence, reasoning that connects the claims and evidence, and a rebuttal of counter-arguments</td></tr>
<tr><td colspan="3">Claim addresses question asked</td><td colspan="3">Claim addresses question asked with a causal account</td></tr>
<tr><td colspan="3">Component (i.e. evidence, reasoning, rebuttal) is appropriate.</td><td colspan="3">Component (i.e. evidence, reasoning, rebuttal) is appropriate and sufficient.</td></tr>
</table>

Argumentative process	Teacher is a primary participant in the argumentative discourse	Teacher facilitates students in arguing with one another	Students are primary participants in the argumentative discourse
	Claims are articulated, defended and questioned	Claims are articulated, defended, questioned, and evaluated	Claims are articulated, defended, questioned, evaluated, and revised

Although each dimension is described in terms of discrete categories along the progression, there is in reality a great deal of variability in each section resulting in the progression being more of a continuum than discrete steps. In this section, we use the 12th grade biodiversity argument to illustrate each of these dimensions and the continuum of student progress along these dimensions.

Problem context

The first dimension of the learning progression focuses on the problem context. Argumentation requires that the problem context be rich enough to enable multiple perspectives (de Vries, Lund, & Michael, 2002). Moreover, the context must require the use of evidence to reconcile these multiple perspectives (Hatano & Inagaki, 1991; Osborne, Erduran, & Simon, 2004). As stated by Hatano and Inagaki "…constructive group interaction is often induced when group members talk about a set of clearly articulated alternatives that are falsifiable by empirical means" (p. 334). The literature on scientific argumentation in classrooms provides ample examples of problems that require students to make sense of evidence. For example, Blumenfeld et al. (1991) talk about students designing artifacts that require them to use complex thought to integrate multiple pieces of information. In the work by both Hatano and Inagaki (1991) and Osborne, Erduran and Simon (2004) we see the researchers presenting students with differing claims in which each claim is plausible, depending on their interpretation of the evidence. In each of these examples, researcher/designers create situations in which the students have a need to use data; the students are going beyond stating the data in order to apply it as evidence to solve the problem. Thus, when considering the complexity of the problem, we are doing so with the expectation that all argumentative problems will have multiple plausible answers that can be evaluated with available evidence. Within that expectation, our learning progression identifies three leverage points that can alter the complexity of the problem: the complexity of the question, the size of the data set, and the appropriateness of the data.

We define the complexity of the question in terms of the clarity of the problem space. In particular, we are interested in the degree to which the possible answers to the question are defined and their plausibility. It is important to note that, within this definition we maintain the expectation that questions at all levels of complexity be open-ended. As explained by Krajcik and Czerniak, when asked an open-ended question, "students can respond in a variety of ways, and the teacher may not know the answers to the questions asked" (2007, p 280). This openness creates the possibility that students may have divergent answers—that they may have a need to argue. For example, in the bird

biodiversity example, there are three possible answers to the question (Area 1, 2 or 3). Thus, this question is at the first stage of complexity for this characteristic. That said, each of these answers are plausible. For example, a student may argue that a golf course increases biodiversity because of the increased grass and water while another could argue that the more urban neighborhoods might have more biodiversity because there is a wide variety of food sources. Thus, while being well-defined, this question fulfills our expectation that the students debate an open-ended question with multiple plausible answers.

The remaining characteristics in this dimension, the size of the data set and the appropriateness of the data, focus on the information students will have available to answer the question. The size of the data set characterizes the number of data points or data representations with which the students are working. The appropriateness of the data speaks to whether there is irrelevant information included in the dataset. That is, the most simple data students could interpret to answer a question would be data that is all relevant such that students are not required to determine which data is extraneous. The problem context increases in complexity as the students are given increasing responsibility for determining which data are germane to the question at hand. For example, in the bird biodiversity problem, the students are given three google maps. These maps narrow the scope of the students search for relevant data. While being small in size, these maps are complex in that they do not restrict the information to only that data that is relevant (or appropriate) to the question. That is, the google maps contain all of the usual cartographical information and it is the students' job to determine what on the map is relevant to a question of biodiversity. For that reason, this question is an example of the second level of complexity for this characteristic: the "data set includes both appropriate and inappropriate data." The most complex level of data size occurs when students define the dataset themselves. In this case, the students are responsible for locating and evaluating the data that can answer their question. Thus, the initial dataset can be thought of as all possible data that the students are then sifting through in order to identify the most relevant and appropriate data.

While most of the characteristics on our learning progression our independent, this highlights that the data size and appropriateness are related characteristic: in order to be at the highest complexity of data size students must also be at the highest complexity of data appropriateness because defining a dataset requires that students differentiate between appropriate and inappropriate data. In addition, making a problem more open-ended often requires larger datasets. For example, to make the bird biodiversity problem more complex, students could be asked to examine the entire city rather than three specific sites. This is both more open-ended and requires a larger dataset. Thus, while it is possible to imagine scenarios in which a question could be open-ended but use a small dataset, we suggest that these characteristics are typically connected to one another.

Argumentative product

Similar to Jimenez-Aleixandre and Erduran (2008), we define scientific argumentation in terms of both the written and spoken products and processes. An argumentative product is a reasoned piece of discourse in which a claim has been justified. An argumentative

process has a more social meaning in that it entails a dispute or debate between multiple people. Both aspects are essential for science education and we discuss them as different dimensions of scientific argumentation. When focusing on the argumentative product dimension, our learning progression identifies three characteristics that can change in complexity: 1.) the components in the argument and 2.) the appropriateness of the claims and 3.) the appropriateness and sufficiency of the information included in defense of the claim. We explore each of these characteristics in this section.

Following trends in the field of science education, as reviewed by Sampson and Clark (2008), we use Toulmin's model of an argument (1958) in order to identify the basic components of an argumentative product for k-12 students. Figure 1 depicts a simplification of Toulmin's (1958) framework and the relationships between these components (McNeill & Krajcik, in preparation).

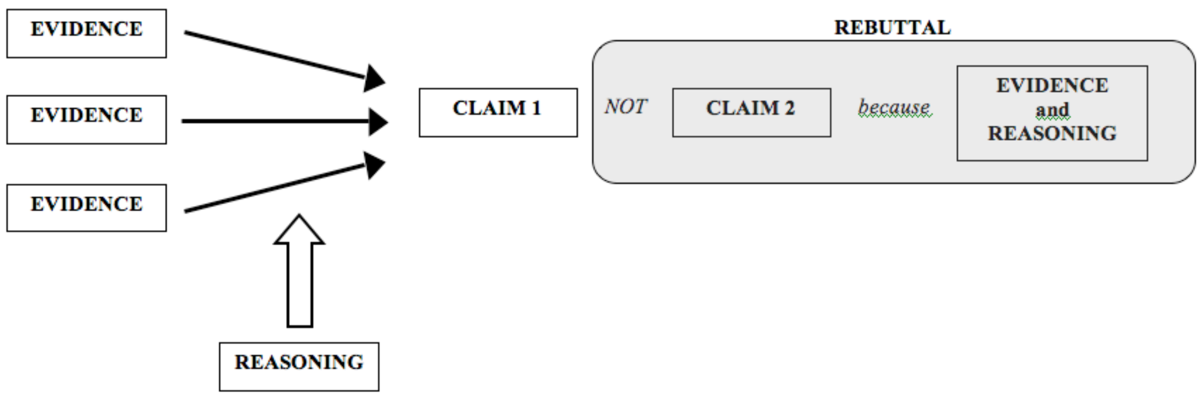

Figure 1: Simplification of Toulmin's framework (McNeill & Krajcik, in preparation)

In this framework, the claim is the answer to a question or a problem. Evidence is the scientific data, which are used to support the claim. Scientific data is information, such as observations and measurements, that can either be collected by the students themselves (i.e. first hand data) or be collected by another individual and provided to the students (i.e. second hand data). Typically, scientists' selection and use of scientific data is influenced by their understandings of scientific principles (T. S. Kuhn, 1970). The reasoning articulates the logic behind that choice and articulates why the evidence supports the claim. Finally, the rebuttal makes a claim about why alternative arguments (counter-arguments) are incorrect and uses additional evidence and reasoning to justify that rationale.

Not only is the inclusion of each of these components important in an argumentative product, but the quality and complexity of each component must also be considered. First, we examine the complexity of the claim. At the first level of complexity, claims address the question asked. While a relatively simple requirement, examples below will demonstrate that not all student arguments focus on the question asked. At the second level, claims include a causal account. That is, rather than simply identifying an area with

high biodiversity, students might be asked to explain why one area has more biodiversity than another.

As depicted in Table 1, we also assess the appropriateness and sufficiency of the evidence, reasoning and rebuttal. Each of these three components is considered in relation to the claim that a student constructs. By appropriate we mean that the evidence, reasoning and/or rebuttal are relevant to the problem and scientifically accurate to support the claim a student is making. Students can have difficulty understanding what data is and is not appropriate to support their claims. For example, in a middle school chemistry unit we found that students would rely on mass to determine whether two unknowns were the same substance, which is not a scientifically accurate characteristic to use to identify a substance (McNeill & Krajcik, 2007). By sufficient we mean that the quantity or complexity of the evidence, reasoning and/or rebuttal is able to convince an audience of the claim. For example, science activities often ask students to analyze multiple pieces of data, and then ask a question that requires students to incorporate each of the data points into their argumentative product. Instead of utilizing the multiple pieces, students may focus on one data point. This would be considered insufficient to justify their claim.

In general, we suggest that students' argumentative products increase in complexity as they take on more and more of the supportive components of an argument—evidence, reasoning and rebuttals—and as those components become increasingly appropriate and sufficient. At the first level of the argumentative product dimension of the learning progression (see Table 1), we are looking for students to defend their claims. In making this the first step in the progression we have skipped the more obvious first step of asking students to make claims. We did this for two reasons. First, our experience demonstrates that students frequently make claims in class discussions. They make claims in response to direct teacher questions (i.e., in the example discussed in this paper, a student could make a claim in response to the question: "where do the birds have the greatest biodiversity?") without ever justifying or supporting their response. Thus this component of the argumentative product does not require additional support or curricular focus. Moreover, we suggest that a claim must be defended in order to be part of an argument. That is, if a student responded to the teacher question regarding biodiversity by making the claim "Area #1" and the teacher evaluated that claim as correct or incorrect, they would not be engaging in an argument. Instead, they would be engaged in a more stereotypical classroom interaction in which the teacher was assessing whether students knew the facts without considering their reasoning (Lemke, 1990; Mehan, 1979). Thus, our learning progression begins with students both making and *defending* their claims.

We suggest that this component of the argumentative product—the defense of claims—should become a norm of the classroom interactions. That is, the science classroom community (the students and teachers) should expect that ideas (their predictions, hypotheses, inferences and conclusions) be supported. This expectation will make it possible for students to debate the merits of their different ideas by shifting the focus away from the ideas and authors of those ideas to their respective supports. In this way, the conversation should shift from determining whether claims are correct (whether they have been validated by experts such as the teacher) to whether claims are plausible given the evidence and science. This shift means that students are positioned to be constructors,

evaluators and critiquers of knowledge. In other words, this shift means that students are positioned to engage in the argumentative discourse.

Developing this norm of defending the claim can begin immediately when a class focuses on argumentation—it begins with the teacher consistently asking students why they make the claims they make and discussing the students' reasons. It is a norm once the students start spontaneously defending their claims and looking for these justifications without teacher prompting. While important, the development of this norm will take time and should not prevent work on the additional argument components. Thus, we suggest quickly moving from step 1—defending claims—to refining those justifications so that they include necessary and sufficient evidence, reasoning and rebuttals.

We illustrate these characteristics of the argumentative product using one high school student's written response to the biodiversity question (we have labeled the claim, evidence, and reasoning in this response):

> *Comparing the three sites I would expect the second site to have the highest bird biodiversity* (CLAIM). *One because there is a good amount of trees* (EVIDENCE) *to get food* (REASONING). *There is different types of places* (EVIDENCE) *they can go to in site two* (REASONING).

This written argument includes appropriate, but insufficient, evidence and reasoning to defend the claim. For example, the student could elaborate on why food is important for biodiversity and why a site containing different types of places is important to prove her claim. The written argument does not include a rebuttal. Given this constellation of characteristics, we characterize this argument as being relatively complex with respect to the components included, but relatively simple when considering the depth of those components.

We and others (Osborne et al., 2004) have found that rebuttals are the hardest element for students to incorporate into their writing—they require that students identify possible counter-arguments to rebut by thinking about the argument from some one else's perspective, and then identify evidence to disprove those counter-arguments. Thus, we see arguments that include rebuttals as being the highest level of complexity. While students rarely include these in their writing, they are more likely to include rebuttals in verbal arguments, without instruction. The following transcript provides an example of an instance in which a student rebutted a counter-argument. This exchange occurred approximately ten minutes into the biodiversity discussion and begins with Simone making the claim that Site #3 would have the highest biodiversity and providing evidence and reasoning to defend her claim. She then provides a rebuttal to an earlier argument that the birds would not want to live in Site #3 because it was a golf course. The rebuttal is underlined and in italics. The fourth column identifies the ways in which this discourse satisfies particular aspects of the argumentative process (discussed in the following section).

Transcript 1: Exemplifies a rebuttal appearing in a class argument

Line	Participant	Transcript – Argument Product Identified	Argumentative Process

1	Simone	I said three (CLAIM) because there's less distraction. There's not a lot of noise (REASONING) and even though there's a street right there, they still have all - for three they still have a lot of places to go, like what Chloe was saying. They still like have places to go – that is what she said (EVIDENCE). *But I wouldn't agree with golf course either because that does not have anything to do with it. There's other places they can go. (EVIDENCE)*	Stating and Defending Evaluating
2	Mr. Dodson	When you say you don't agree with the golf, what do you mean?	Questioning
3	Simone	*Like they were saying that they think the golf – the golf course will be a distraction for the birds and stuff (REASONING). I don't agree with that because…. the golf course is like more open. They have all that space right there (EVIDENCE).*	Evaluating

Argumentative process

To explore the argumentative process—the discourse moves that occur between multiple people—we combined work by Erduran, Simon and Osborne (Erduran, Simon, & Osborne, 2004) with descriptions of classroom discourse that are characterized as representing a culture of scientific inquiry (e.g., Brown & Campione, 1996; de Vries et al., 2002; Engle & Conant, 2002; Hogan & Corey, 2001; Scardamalia & Bereiter, 1994). Based on this and earlier work by the first author (Berland, 2008), we've identified four discourse characteristics that are key to the argumentative process:

1. Individuals stating and defending claims
2. Individuals questioning one another's claims and defense
3. Individuals evaluating one another's claims and defense
4. Individuals revising their own and other's claims

Table 1 illustrates how these characteristics are incorporated into our learning progression. At level 1 of the progression, claims are being stated, defended (characteristic 1) and questioned (characteristic 2). Level 2 of the progression adds the third characteristic to the discourse: claims and their defense are now evaluated as well. Finally, level 3 encompasses all 4 characteristics—it includes the stating, defending, questioning, evaluating and revision of claims. We discuss and illustrate each of these levels in more detail in this section.

We suggest that engaging in argumentative discourse at the first level of complexity requires that participants make and defend claims and question one another's claims and defense—characteristics 1 and 2 on the above list. This process is a social process that occurs between the individuals in the room (or in the online environment) in that

participants interact with one another, building the argument together by asking and responding to questions. In focusing on questions, we are expecting that the questions go beyond a typical teacher-student interaction in which a teacher asks a question—either one with a known answer (e.g., What is the definition of biodiversity?) or a more open-ended one (e.g., Which site has the highest biodiversity?)—and accepts or rejects a student answer without further discussion and debate. Instead, in terms of scientific argumentation, we expect the questions asked to challenge and problematize the ideas under discussion. That is, rather than treating science ideas as facts to be evaluated (as in a traditional IRE exchange, Mehan, 1979), the goal is to develop learning environments in which students provide claims that can be questioned and evaluated in dialogic interactions within the classroom community. Thus, our learning progression states that the first level of complexity requires that the participants interact with one another's ideas—that they are not simply accepted by the teacher. For example, below we discuss example 2 from a 5th grade classroom in which students' responses are simply accepted without any debate. Each student response is disconnected from their peers' ideas and simply evaluated by the teacher. This example is below level 1 of our progression because the ideas are not being problematized or questioned in any meaningful way.

At the second level of complexity we move beyond the expectation that ideas be questioned to include the evaluation of those ideas. However, as with the expectation that ideas be questioned, we define evaluation to be more than the simple treatment of student ideas as facts to be evaluated and instead, it is an opportunity to challenge the ideas under discussion. At a basic level, this can be accomplished when one explains their evaluation of a participant's idea. Transcript 1 illustrates this. It includes both questioning (e.g. Mr. Dodson asks "what do you mean?) and evaluating (e.g. Simone evaluates a previous student's argument by explaining why she does not believe that the golf course would be distracting to the birds).

At the third and final level, we expect that the participants revise their ideas in light of the competing arguments they have discussed. This third level is rare (Berland & Reiser, in preparation). Evaluating and critiquing arguments frequently frames the argumentative activity as competitive such that students are not in positions to consider the strengths of those arguments. In this situation, students are unlikely to revise their own thinking in light of their classmates' arguments. Thus, when considering a learning progression for scientific argumentation, we suggest that the complexity will increase as students take on more of these moves in talk and in writing (e.g. online environment). This shift occurs gradually as the instructional environment supports students in taking on each of the discourse characteristics and as these characteristics become the norm for classroom discussions. That is, engaging in all of these discourse characteristics requires that students learn that science class is a place for collaborative knowledge building with evidence, rather than a place to demonstrate individual expertise. It is when this expectation or norm is in place that all of these discourse characteristics will be a sensible part of the students' practice (Berland, in preparation).

One way the instructional environment can scaffold this process is by the teacher taking on the discourse characteristics that the students are not yet demonstrating. In this way the teacher can model the process and communicate the expectation that students will be doing these things. Thus, another element on our learning progression examines the

involvement of the teacher. For example, at the first level in the learning progression, a teacher might be a primary participant in the argument such that they model how to engage with these discourse characteristics. At the second level, a teacher might facilitate students in taking on these discourse moves by prompting them to respond to their classmates' ideas and/or revise their own. At the final level, students should be spontaneously responding to the ideas being discussed by questioning, evaluating, critiquing and revising them.

The example of student discourse provided above in Transcript 1 illustrates an interaction at the middle level of complexity in terms of the argumentative process. The student has made and defended her claims. In addition she is evaluating and critiquing the claims of her classmates. Moreover, the teacher is questioning the ideas and facilitating the students' interactions with one another's ideas. This argument would be at the highest level of complexity if the students were directly responding to one another (rather than responding to a teacher prompt to evaluate a classmate's ideas) and if there was evidence that they were revising their thinking in light of the discussion.

Three Classroom Examples of the Dimensions of the Learning Progression

In the previous section, we used one example from a 12th grade classroom to illustrate the different dimensions of the learning progression for scientific argumentation. We will now describe three other examples in order to illustrate other ways classroom talk and writing can be mapped onto the learning progression as well as to explore the ways that design choices in curriculum and teacher instructional strategies can potentially influence the complexity of the students' argumentative products and processes. Figure 2 provides an overview of how the four examples all map onto the learning progression. The solid black line illustrates Example 1, which we just discussed. The problem context is simple in terms of the openness of the question and the dataset is small, yet it is more complex in terms of the inclusion of both appropriate and inappropriate data. Notice that the line splits in the "argument product" dimension. This split represents the differences that emerged in the students' verbal and written argumentation: their verbal argumentation represented a more complex argument than their written. Finally, the argumentative process is also in the middle in terms of the role of the teacher and the characteristics of the classroom discourse.

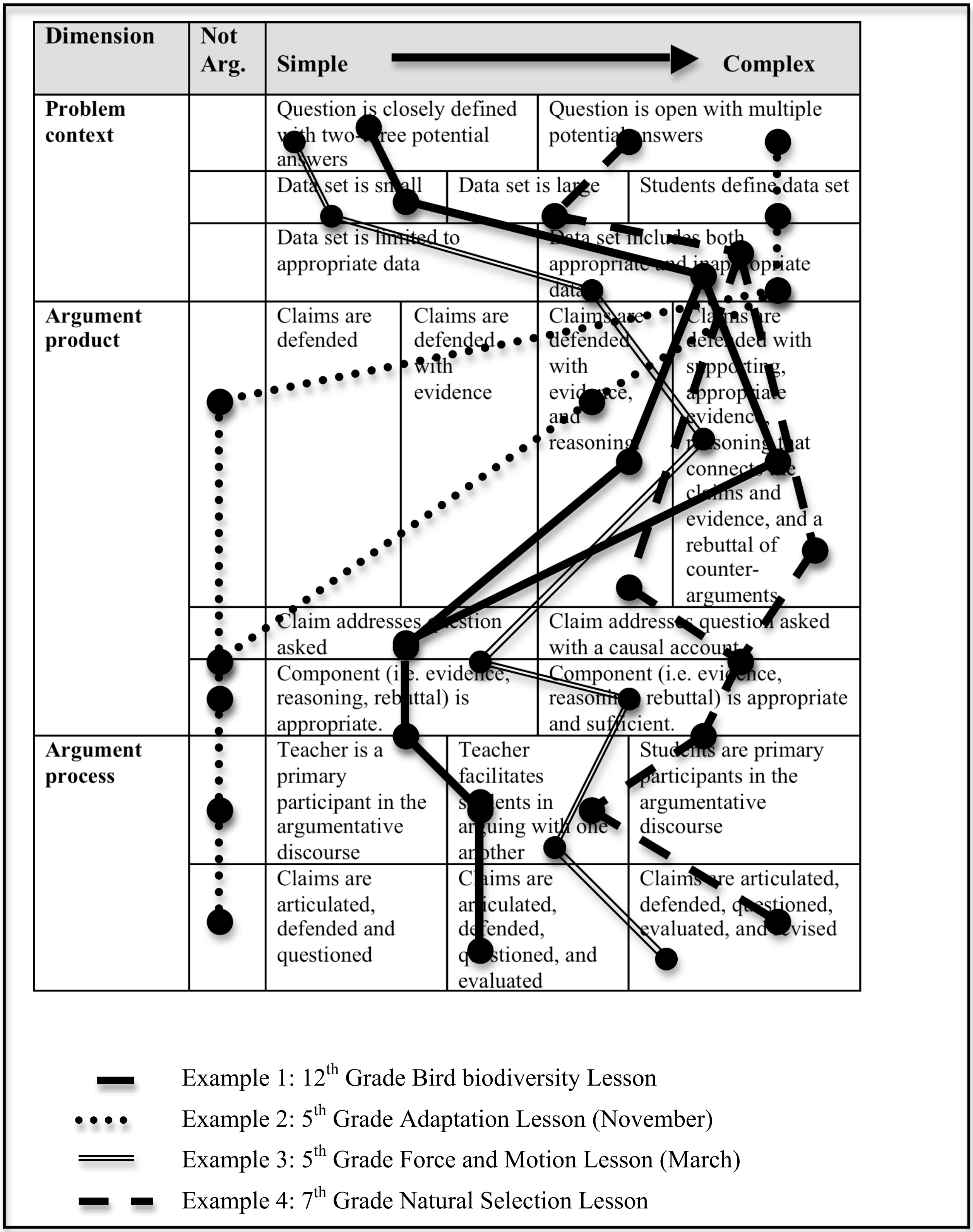

Figure 2: Four Classroom Examples Mapped onto the Learning Progression

When examining Figure 2 it is important to recognize that the placement of the lines in each cell was an aesthetic decision rather than a communicative one. For example, three of the four examples have argumentative products at the highest level of complexity (containing claims, evidence, reasoning and rebuttals). The lines for each of these examples pass through different points in the cell to minimize overlapping lines, not because one example was more sophisticated than another.

Looking across the ways in which student argumentation mapped onto the learning progression for the 4 examples we discuss in this paper, as seen in Figure 2, highlights that progress through the individual dimensions of the learning progression is not uniform—that is, being in step 2 of the problem context does not suggest that students will be at step 2 in their argumentative product. In fact, rather than revealing that there is parallel movement through the dimensions, Figure 2 reveals that there are numerous paths through them. For example, in example 1, the problem context was relatively simple while the product and process were in the middle of the progression. In contrast, as will be discussed at more length in the following sections, students in example 2 were given a complex problem context and their argumentative products and processes were quite simple—at times they were not argumentative. This comparison emphasizes that the relationship between these dimensions is complex. Moreover, Figure 2 reveals that progress is not age dependent. In fact, examples 3 and 4 represent students working at a more sophisticated level than the students in example 1 but the example 1 students are seniors in high school while the others are in fifth and seventh grades, respectively. In the following sections we will describe these individual examples and then conclude by looking across them to discuss these and other implications with respect to understanding and supporting students work in scientific argumentation.

Example 2: 5th Grade Adaptation Lesson

Classroom and curricular context.

Examples 2 and 3 both come from the same urban 5th grade science classroom during the 2008-2009 school year. This class is part of a public elementary school in a large urban district in New England. The elementary school is a pilot school, which means that, although it was still apart of the public school district, the school had greater autonomy over budget, staffing and curriculum. The elementary school was a school of choice in that students either selected or were randomly placed in the school based on a lottery system. The majority of the elementary students lived in the surrounding neighborhood. The student body at the school was ethnically diverse with approximately 15% African American, 60% Hispanic, 12% white, 12% Asian, and 1% Other. Approximately 82% of the students attending the school were eligible for free or reduced lunch. The teacher, Mr. Cardone, was a white male who was one of two science specialists in the elementary school. He taught 3rd, 4th and 5th grade science. Mr. Cardone had been teaching elementary science for 6 years at the time of the study. Both examples come from a larger study, which examined the impact of integrating the claim, evidence and reasoning

argumentation framework (McNeill & Krajcik, in preparation) on the students' writing and talk over the course of the school year.

Problem context.

Example 2 occurred in the beginning of November during a curricular unit focused on ecosystems. Approximately one month earlier, the class had used 2-liter bottles that contained both aquatic and terrestrial organisms to create eco-columns. The students then recorded their observations about their eco-columns in their science notebooks every week. During the Example 2 lesson, Mr. Cardone wanted the students to use their observations in their notebook, as well as current observations from their eco-column, to write a scientific argument. He provided the students with the following writing prompt: "Use your ecocolumn to develop a scientific argument about some of the adaptations of one of the organisms found there." Mr. Cardone also told his students: "We will get into our arguments. I want you guys to pick one organism, and start to write an argument with a claim, supporting evidence and then the reasoning for that." The students were not provided with any additional written support; however, Mr. Cardone did circulate around the room as the students were writing and helped students with their arguments. After writing their scientific arguments, Mr. Cardone asked a couple of students to share their writing out loud and the class discussed their argumentative products.

In terms of the problem context, this lesson was more complex than the previous example from the 12th grade classroom. The question is open with multiple potential answers, because the students could choose different organisms as well as different adaptations to focus on in their argument. The students also defined their own dataset by selecting from all of their observations, which meant the dataset was potential large and could include both appropriate and inappropriate data to justify their claim. Consequently, although the students are younger the problem context was designed to be more complex than the high school example.

Argumentative product.

At the end of class, Mr. Cardone asked three different students to share their written arguments. Below is the transcript from two students sharing their responses. In the transcript, we identify the argument product in terms of claim, evidence and reasoning. These classifications were not part of what the students read.

Transcript 2: Exemplifies the argumentative product in Mr. Cardone's class' November lesson

Line	Participant	Transcript – Argument Product Identified	Argumentative Process
1	Mr. Cardone	Well would somebody share their claim and then argument, please, Antonio. Thank you, you had, you had a good one, right? Let's hear what Antonio has to say. First we want to be listening for what his	

		claim is what his evidence is and then what his reasoning is. If you have a claim, evidence of how it survives and reasoning.	
2	Antonio	This one I didn't finish.	
3	Mr. Cardone	Okay, well do the first one that you did finish.	
4	Antonio	Okay, the reptile lives in the cage he eats crickets and he eats worms…	
5	Mr. Cardone	Antonio, okay do the fist one because that ones finished. Okay, well let's hear what you have.	
6	Antonio	Our fish ate one of our dead fish (CLAIM). We believe that our fish and snail ate one of our fish (CLAIM).	Stating
7	Mr. Cardone	Mercedes	
8	Mercedes	Um, the snail in our environment is helping (CLAIM). He is cleaning the water and the water seems clearer. It also smells better then before, the snail has algae on its shell and the fish is eating from it. The evidence that I have is the new fish lasted a longer time then the other fish we had. (EVIDENCE) And I think it's because the snail cleaned the environment. (REASONING)	Stating and Defending
9	Mr. Cardone	Okay, that was excellent. So, Mercedes said her claim was that the snail was helping clean the environment in her aquarium. Her evidence was that the new fish they added has lasted longer then the old fish. The water appears clearer and it doesn't smell bad, as it used to, and the snail is also helping because she said that there's algae or stuff growing on the shell and she's seen the fish kind of eating it off the shell. Okay, nice job guys. This is, I know, we're just kind of starting to build these arguments but we're going to continue working on this and keep coming back to making the claim, providing your evidence and then the reasoning for why that is a good argument. Okay? So please	

		put your notebooks in your folder.	

In the case of Antonio and Mercede's arguments, neither argument addressed the question asked by Mr. Cardone that focused on the adaptations of one of the organisms in the eco-column. Instead, Antonio's claim focused on which organisms were eating the other organisms and Mercede's claim focused on the role of the snail in the eco-column instead of the adaptations of the snail. Consequently, in terms of the learning progression, both students' responses are considered to be off the chart in terms of whether the claim addresses the question asked—their claims are not answering the question. In terms of whether the claim was defended, Antonio's claim was not defended so it would also be off the chart in terms of including the components (e.g. evidence and reasoning) and the appropriateness of the components. Mercede's did defend her claim with evidence and reasoning. Although her evidence is appropriate, her reasoning is very weak; furthermore, neither component is sufficient to support her claim. Thus, although the problem context was more complex than the high school example, the actual products students' constructed were much simpler.

Argumentative process.

In terms of the argumentative process, we suggest that this example is not a form of argumentation because engagement in argumentation requires, at its core, that the ideas being discussed be questionable—that all participants have the opportunity to question, evaluate and challenge ideas. This discourse is a traditional IRE exchange with the teacher exhibiting an authoritative position in that he was evaluating the students' responses. Here, both students read the argument they wrote, but those arguments are not questioned and discussed. After Antonio read his argument, Mr. Cardone directly called on Mercedes without discussing or even acknowledging what Antonio had read. When Mercede's finished reading, Mr. Cardone commented: "that was excellent," thereby evaluating her response without discussing it. This leaves open questions such as: why was her argument excellent? Was it better than Antonio's? Thus, in this exchange, the ideas are not questionable, instead the teacher has the authority to accept them or not. Furthermore, each student comment is completely disconnected from the ideas of his or her peers. The conversation does not support students in the argumentative process in that students are listening to, building off or critiquing each other's ideas. Consequently, we suggest that this is an example of a non-argumentative class discussion in which students were presenting their argumentative products.

Example 3: 5th Grade Force and Motion Lesson

Problem context.

Example 3 comes from the same classroom, but 4 ½ months later in the school year and focuses on force and motion. During this lesson, the students worked in groups to complete a sheet that addressed the question: "How can you design a car to go the fastest?" The students were asked to circle the choices that they believed would create the strongest argument. They were asked to circle 1 of 3 possible claims, 2 of 6 possible

pieces of evidence, and 1 of 3 possible reasoning statements. The students discussed these different choices in small groups and then came to a decision as a group. Mr. Cardone then led a class discussion in which the student groups debated the strongest choices for claim, evidence and reasoning. He first had each of the six groups share their choices and then he had students debate which choice was the strongest for the different components of the argument product.

As a result of Mr. Cardone's experiences with his students in the fall, he felt the students needed more structure and support in order to both write strong arguments and engage in argumentative discourse. Thus, In terms of the problem context, this lesson is much simpler than the class' adaptation lesson in November: the question is closely defined with only three potential choices; the dataset is also small since the students were given only six pieces of data; and the choices included both appropriate and inappropriate data for the claim.

Argumentative product.

Over the course of the discussion, students offered and debated different claims, evidence and reasoning to answer the question about how to design the fastest car. By the end of the discussion, the students agreed that the following components would construct the strongest argument:

> Claim: The car with the lightest load being pulled by the largest force will go the fastest.
>
> Evidence 1: The car with only one block on the car took 1 second to travel across the table while the car with three blocks took 3 seconds.
>
> Evidence 2: The car that was pulled by 5 washers took 2 seconds to travel across the table while the car with 1 washer took 7 seconds.
>
> Reasoning: The speed was determined by how many seconds it took for the car to travel across the table. The car with less blocks had a lighter load and it traveled faster. The car that was pulled by more washers was pulled by a greater force and it traveled faster.

In terms of the question, the claim does answer the question asked, but it does not provide a causal account. Consequently, we classified the claim at the first level for the argument product. During the course of this discussion, not only were claims, evidence and reasoning provided, but students also provided rebuttals for why the counter arguments were not as strong. Because all four components did surface during the discussion, we classified the product as the highest level for the components included. Finally, students' evidence and reasoning were appropriate and sufficient for the question posed. Consequently, we also classified this category as the most complex level on the learning progression. Although the problem context was simpler than example 2, the products the students constructed were more complex in terms of the claim answering the question and students justification of that claim with evidence and reasoning.

Argumentative process.

The class discussion around the different components was also more complex in terms of argumentative process in that claims were stated, defended, question, evaluated and revised. The transcript below is from when the class began to debate which two pieces of evidence (A, B, C, D, E or F) offered the strongest support for the claim. Originally, the six student groups had a great deal of variation in their evidence choices: two groups select D and F, two groups select A and D, one group selects A and F, and one group selects B and F. Mr. Cardone began the debate by discussing Evidence A. In terms of the argumentative process, the evidence the students are providing is actually the focus of the debate. Consequently, selecting a specific piece of evidence as the strongest (e.g. Evidence A) is the claim, which the students then defend and discuss with their peers. The transcript below illustrates the argumentative process in terms of identifying when students and the teacher were engaged in the various characteristics.

Transcript 3: Exemplifies the argumentative process in Mr. Cardone's class March lesson

Line	Participant	Transcript	Argumentative Process
1	Mr. Cardone	Does anybody think A is good evidence based on what they heard? Kendell, explain why?	Questioning
2	Kendell:	Well I agree with, I disagree with every group except for that group, no because we have the same thing.	Evaluating
3	Mr. Cardone	But, what about it, why? Why are they making a good point about A?	Questioning
4	Kendell	It showed, it like, how the first one says it was the car with the lightest load being pulled by the largest force will go the fastest. I looked at that and then I looked at this and it's like a little bit goes faster.	Defending
5	Mr. Cardone	Okay, so it's saying a lighter load goes faster.	
6	Kendell	goes faster.	
7	Mr. Cardone	Okay so it's saying a lighter load goes faster. And that's what your claim says isn't it?	
8	Kendell	Yeah.	
9	Mr. Cardone	Do they use real numbers in their	

		evidence?	
10	Kendell	Um, Yeah.	
11	Mr. Cardone	Right here, they're using real numbers aren't they? They're using a real load, they're using a real time, so they're suggesting the lightest thing is going to, to the fastest. Do you agree with that?	Questioning
12	Lucia	I've changed my mind, and I agree with this table because, um, maybe it doesn't, maybe the block can be very, very light and the 3 blocks maybe doesn't bring as much weight to the car and maybe it can run faster. So it depends mostly on the block you use.	Revising

Over the course of the discussion, all four characteristics of the argumentative process emerged, which is why we classified this example as the most complex level in terms of this aspect. This section of the discussion begins by Mr. Cardone asking whether anyone thinks that Evidence A is good evidence. Kendell then evaluates another group who selected different evidence. In doing so, he successfully defends his own choice of Evidence A as good evidence. Mr. Cardone questions Kendell to encourage him to elaborate on his response as well as connect to the idea that Evidence A includes numerical data. After their exchange, Lucia then joins the conversation and states that she has revised her claim based on what Kendell's table stated. The teacher, Mr. Cardone, plays an important role in facilitating students in arguing with each other. The students are clearly linking their ideas to other students in the room, but Mr. Cardone is orchestrating those connections. Consequently, in terms of this aspect of the argumentative process we classified the example as the middle level of complexity.

Although the problem context was more closed and simpler for the students compared to the example in November around adaptation, the argumentative product and argumentative process were much more complex. During the time between the two lessons, the students also wrote three other arguments and the teacher integrated the language of claim, evidence and reasoning into the classroom. Therefore, the increased complexity of the product and process cannot be solely attributed to the differences in the problem context. Yet it does illustrate that a more complex context does not necessarily result in a more complex argumentative product or process. Rather the design of the context provides an avenue to support students in scientific argument. Furthermore, this second example from the 5th grade illustrates more complex products and processes than those that emerged in the 12th grade classroom. This demonstrates that elementary students can be expected to productively engage in this practice.

Example 4: 7th Grade Natural Selection Lesson

For our fourth and final example of students engaging in scientific argumentation, we draw from a class of 7th grade students as they worked with a software environment designed to foster discussion about natural selection. This environment was designed by Tabak, Sandoval, Reiser and Steinmuller (2000) and adapted to work with the IQWST middle school science curriculum by Finn and colleagues (Finn, Kuhn, Whitcomb, Bruozas, & Reiser, 2006). The class we examine here was using a pilot version of this IQWST curriculum. Before exploring their argumentation we provide background information regarding the classroom community and the problem context.

Classroom and curricular context.

Ms. B taught in a grades 7-12 magnet school in an urban, Midwestern school district. Ms. B is a white female and she had been teaching for about five years when this study was conducted. This school is located a few blocks from a private university and the neighborhood is home to an affluent African-American population. Entry into this school is based on test scores in reading and math and the junior high school students seem to view this school as a “prep” school for getting into one of the city’s “good” high schools (including this one, as enrollment in the middle school does not guarantee enrollment in the high school). About 95% of the junior high students in this school are African-American and about 62% are on the free or reduced lunch program.

The example on which we focus in this paper comes at the conclusion of an 8-week unit on ecosystems. Through this unit, the students engaged in three lessons explicitly designed to foster their engagement in argumentative discourse. It was hoped that these lessons would create opportunities for students to practice argumentation and develop norms around the ways that they justified their claims and the criteria they used to evaluate their classmates’ ideas. We see evidence that these norms developed through these interactions when students did things like demand that their classmates use empirical evidence to support their claims.

Problem context

For this example we focus on a single group of students as they engaged in an activity exploring natural selection. In this activity, students were working with a software program that enabled them to investigate data showing the characteristics of Ground Finches on the Galapagos Islands before and after a catastrophic event. This data included the wingspan, weight, beak size and habits of individual birds before and after the event, as well as environmental data (i.e., rainfall and temperature). Students worked with this database to create graphs that highlighted the relationship between each of these data points (Finn et al., 2006; Tabak et al., 2000). We suggest that, although this data is a large dataset, it is not student defined (students are given the dataset). This characterization places the question at the middle level of complexity for this characteristic. In addition, the data includes a mix of relevant and irrelevant data; A large part of the students’ job was to sift through this data and determine which to use. Thus, it is at the highest level of complexity when examining the data appropriateness characteristic.

These students used this data to explore the question: "Why did most of the finches die in 1973 and some survive?" In addition, they had been given a worksheet that identified three sub-questions that their answer should include. These were:

1. What **environmental change** affected the finches' survival?
2. What **trait** affected the finches' ability to survive the environmental change?
3. How did that **trait affect the finches ability to survive**? (emphasis in original)

We have identified this as a "complex" question because there are multiple plausible answers to each of these sub-questions and there are many ways to fit these pieces together into a coherent account of the finch phenomenon.

The students were scaffolded through their investigation with both worksheets and activity structures. The worksheets students used highlighted the sub-questions mentioned above and clearly articulated expectations for the students' answers. These expectations communicated the consensus that emerged out of the students' prior experiences investigating complex questions such as this and included ideas such as:

1. Explanation specifically describes what happened.
2. The explanation is possible because there is evidence about finches and the Galapagos Islands that supports it.
3. The evidence came from observations, experiments or historical data and is *not* opinion.
4. There is enough evidence to support the entire explanation and to connect to the *big ideas*.

The worksheet also guided students through the process of answering these questions and the various activities in which they would engage, including:

1. Student pairs worked together to construct initial answers to the questions listed above
2. Two different student pairs combined to form a group of 4. As a group they evaluated the pairs' individual explanations of the finch phenomenon (using criteria such as those listed above) and worked together to construct a single explanation with which everyone in the group agreed. This activity is called an Argument Jigsaw and is described at more length in Berland and Resier (REF).
3. Each group then presented their idea to the class and the class discussed their different ideas and evidence.
4. Finally, the groups reconvened after the whole class discussion and worked to address any problems that their classmate's identified with their answer.

In the example that follows we explore one student group as they worked on step 2 of this process – coming to consensus regarding the finch mystery. This activity was designed with the expectation that it would facilitate student engagement in scientific argumentation because it necessitates those interactions: the students entered these discussions with competing ideas and were tasked with coming to agreement.

Argumentative product and process

The following transcript illustrates the students' interactions around the finch mystery and their argumentative process for moving towards a single answer. This exchange begins shortly after Janelle and Jalen and Peter and Toby each presented their individual arguments to one another. In short, Janelle and Jalen have determined that the finches died because a drought killed their food while Peter and Toby have decided that excessive rainfalls killed the birds' food. In the exchange that follows Janelle and Toby work to reconcile these opposing claims.

Transcript 4: Exemplifies the argumentative discourse in Ms. B's class

Line	Participant	Transcript	Argumentative Process
1	Janelle	What I notice is that your claim and our claim are opposite.	Evaluating
2	Toby	Yeah.	
3	Janelle	Because we say it's from the drought and you say it's from harsh rain.	
4	Toby	Yeah.	
5	Janelle	And our evidence from that is that we actually have measurements that says the rainfall decreased (EVIDENCE). Do you have actual numbers that say the rainfall increased?	Defending; Questioning
6	Toby	Yeah.	
7	Janelle	Because you can't say it increased without numbers.	
8	Toby	Yeah.	
9	Janelle	I want to see it.	
10	Toby	Okay. So the rainfall in 1973 seemed pretty devastating (EVIDENCE) to kill all the finches in the wet season (REASONING).	Defending
11	Janelle	But here's the thing: the rainfall is pretty balanced.	Evaluating; Rebuttal
12	Toby	No, I mean, it's not – it's not just going to keep going up, because I remember in 1979 none of the finches really died in the wet season or the dry season (EVIDENCE).	Defending; Rebuttal
13	Janelle	But the rainfall, I don't think it kills the plants. I don't think it drowns them at all	Defending;

		(REASONING).	Rebuttal
14	Toby	It does. That's what my mom says. That if it rains too hard, that it drowns the plants, so they can't survive (REASONING).	Defending; Rebuttal
15	Janelle	I know.	

These students discussed their opposing arguments for the rest of the period. When the bell rang they acknowledged their disagreement and decided that they "should actually get on the computer … [to] look at graphs and make sure" (Janelle, not shown in the transcript, occurred later in the conversation). The following day they did so and concluded that Janelle and Jalen were correct: the birds died because a drought killed their food source. This conclusion is revealed in the final written argument that these students turned in:

> The environmental change that affected the finches' survival *was drought* and the finch population slowly decreased because of this drought (CLAIM). It was an indirect effect, because drought caused (REASONING) chamae seeds and portulaca seeds to be scarce (EVIDENCE), making it so finches with smaller beaks [were] unable to survive dry seasons, since they weren't able to get tribulus and cactus seeds open (REASONING). Only the finches with larger beaks could eat them (EVIDENCE). This, we believe, [this] was the reason why so many finches died, and why some finches were able to survive (emphasis added).

Notice that this process reveals the students engaging in all four discourse characteristics highlighted in our argumentative process learning progression. The students are: defending their claims; evaluating and critiquing ideas, and questioning ideas. Moreover, Toby and Peter's revision of their claim demonstrates the fourth discourse characteristic: these students revised their ideas in light of Janelle and Jalen's contradictory evidence (shown in their final agreed upon explanation). Furthermore, the students are the primary participants in the discussion and are not dependent on the teacher for facilitating their argumentative discourse. Consequently, for both of these aspects of the argumentative process, we classified this example at the highest level of complexity.

In addition, in lines 12-14 we see both Toby and Janelle using appropriate evidence, reasoning and rebuttals to support their claims. However, their written argument is less complex—it does not include rebuttals. Thus, we suggest that their argumentative product during the discussion is at the upper end of the learning progression with respect to the components it includes but that their written product is slightly less sophisticated than their verbal argument.

In terms of the content of their justifications, we can say that these students have used appropriate evidence and reasoning to support their claims but that their justifications are not sufficient. For example, Toby has identified evidence that the rainfall increased and is using reasoning that plants can drown to support his claim that the birds' food died because of torrential rainfalls. As Janelle pointed out (Line 11), Toby's evidence is

insufficient because it does not explain how the plants survived other wet seasons when the rain fell heavily.

Overall, we find this to be an exciting example of students engaging in scientific argumentation: with little variation, the problem context, argumentative product and argumentative process each reveal students engaging at the upper levels of this learning progression. Thus, we see that, unlike example 2 in which the complex problem context resulted in overly simplistic argumentative discourse, these students engaged in a rich problem context in sophisticated ways. Moreover, they did so in the 7th grade. The following discussion explores the implications of this and other cross example comparisons in terms of the ways we can alter learning environments to facilitate different levels of student engagement in this complex practice.

Conclusion

Although an overarching goal of science education is for students to engage in argumentation in which they construct and justify knowledge claims and practice productive social interactions with their peers, these are not the norms of classroom science (Duschl et al., 2007). Learning progressions provide a tool to help students develop more complex ways of thinking about a practice, specifically scientific argument, across time (Smith et al., 2006). Each of the defined dimensions in our learning progression creates an opportunity for educators to support student progress in participating in argumentative discourse. In this discussion we explore how this learning progression can guide educators' work in supporting student engagement in this complex practice.

Designing the problem context

The problem context is something that educators can control—they generally manage the types of questions students are investigating and their access to data. Thus, one way to help students develop argumentative skills is to gradually shift the complexity of these problem contexts. One interesting implication that emerges from the comparison across these examples is that simplifying the problem context may facilitate students in engaging in other aspects of argumentation in more complex ways. For example, in example 3 the students are asked a relatively simple question and engage in the argumentation about it in relatively complex ways. However, earlier that year these same students were asked a complex question that they engaged with in relatively simple ways (this is seen in example 2). There are multiple explanations for this change—one of which is that time had passed and the students developed more argumentation skills. However, considering the challenges the students had with scientific argumentation throughout the year, we suggest that the changing problem context can account for some of this shift: when answering the open-ended question in example 2 the students didn't know what was expected while the more scaffolded format in example 3 guided students in how to construct more complex arguments. Thus, the scaffolds helped students understand the expectations for their participation in this practice.

That is, the simpler problem complex in example 3 provided students with both general support for the argumentation framework of claim, evidence and reasoning as well as context-specific support focused on what counted as each of those components for this particular domain. Providing with both general and context-specific support is one way that educators can reduce the complexity of the problem context—they define the problem space. In addition, providing these supports can enable students to have greater success in scientific argumentation (McNeill & Krajcik, in press). Thus, when designing lessons, curriculum designers and teachers should consider how to develop simpler problem contexts with greater supports for students who have little experience engaging in scientific argumentation. It is not that they should alter their expectations for the outcomes of students, but rather they need to provide students with more support. Over time, the goal is for students to be able to engage in scientific argumentation in the complex problem contexts of everyday life, such as evaluating scientific claims in the media. Consequently, the scaffolds that are provided to students should decrease or fade and the problem context should become more complex over time to support students in independent practice (McNeill et al., 2006).

Although the support provided to students should decrease over time, this does not mean that by the time students are seniors in high school that they will not require any support. Example 1 illustrates the challenges one class of 12th grade students had with scientific argumentation. One explanation for this difficulty is that the students had minimal experience with scientific argumentation in their previous k-12 education. We believe this was part of the challenge for these students. But another aspect that needs to be considered is the science content of the scientific argument. There is a relationship between students' understanding of the science content and their ability to justify claims with appropriate evidence and reasoning (McNeill, et al., 2006). As stated by Osborne, Erduran and Simon "… argumentation of quality is dependent on a body of appropriate knowledge that can form the data and warrants of an individual's arguments" (2004, p. 1015). In other words, students with a stronger understanding of the science content construct stronger scientific arguments, perhaps in part because they have a better understanding of what counts as appropriate evidence and reasoning to justify their claims.

Consequently, we suggest that educators can use the problem context as a tool for supporting students in argumentation in new content areas. That is, as curriculum developers or teachers introduce new science content they begin by posing simpler problem contexts to enable students to maintain the norms they are developing for argumentation and then gradually increase the complexity of those problem contexts as students developer a deeper understanding of the science content. In this case, the complexity of the problem context would move back and forth, while the level of student argumentative product and process would progress through the stages of the learning progression.

Establishing classroom culture and norms

There is a large body of research demonstrating the ways in which existing classroom norms can inhibit student engagement in scientific argumentation (e.g., Berland & Reiser, 2009; Driver, Newton, & Osborne, 2000; Hatano & Inagaki, 1991; M. P. Jimenez-

Aleixandre, Rodriguez, & Duschl, 2000). These and other studies converge on the conclusion that supporting student engagement in scientific argumentation requires that educators focus on developing the norms of this complex practice. In this section, we examine the implications of this from both a product and process perspective.

In terms of the argumentative product, the teacher can facilitate students' development through the progression by first developing a norm, or expectation, that students will defend their answers and then helping to refine those defenses. The refining happens by focusing on progressively more complex components as well as more complex ways of using each of those components. For example, the teacher's first focus would be on including evidence. As students become more adept at including evidence in their written and spoken arguments, the teacher would shift the focus to reasoning and finally, to rebuttals. The complexity of each component can also increase; for example, moving from using one piece of evidence to multiple pieces of evidence, which require greater data reduction and inferences.

Key to this description of the support is that the support that students are asked to provide serves a purpose in the discussion or in their writing. That is, in order to facilitate students engagement in "doing science" rather than "doing the lesson" (M. P. Jimenez-Aleixandre et al., 2000), in order to facilitate the norms of scientific argumentation, students must be in situations in which doing science – turning to empirical evidence and scientific concepts – is sensible. For example, when focusing on evidence, the teacher would create situations in which the students need the evidence in order to differentiate between plausible answers. In these situations students would be developing the norm of using evidence because they would be experiencing its utility (Berland & Reiser, 2009; L. Kuhn & Reiser, 2006).

Developing a classroom culture and norms is also essential for supporting student engagement in the argumentative process—or discourse. First, the above description of creating norms that support student progression on their argumentative products occurs through discourse—it occurs while they are engaged in the process of scientific argumentation. Second, classroom communities must develop norms that facilitate student attention to one another's ideas such that they begin to question, evaluate and revise the ideas being discussed. Examples 1 and 2 in this paper as well as multiple studies examining classroom discourse (e.g., Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Hogan, 1999; Lemke, 1990; Mehan, 1979) reveal that students are rarely asked (or enabled) to substantively engaged with one another's ideas. Moreover, that students rarely do this can inhibit their willingness to do so when put in situations that facilitate these in-depth interactions (Berland, in preparation; Hogan & Corey, 2001). Thus, developing classroom norms that support student-to-student interactions is a key aspect of fostering student engagement in scientific argumentation—of helping them to engage in the process of this discourse practice.

As with the facilitation of the product dimension, teachers can facilitate the creation of these norms by creating situations in which it makes sense for students to engage with one another's ideas. For example, creating situations in which students are asked to reach consensus makes it necessary for them to question, evaluate and revise their differing

ideas (Berland & Reiser, 2009; L. Kuhn, Kenyon, & Reiser, 2006). While designing activities with goals conducive to argumentation, such as this, can facilitate these norms, the creation of new norms takes times. It is therefore expected that the teacher will support students in accomplishing the goal of consensus-building by helping them to differentiate between empirical and opinion-based supports—by helping them refine their expectations for one another's argumentative products. In this way, the norms of developing argumentative products and engaging in the process of scientific argumentation are tightly intertwined and we suggest that educators must work on both, simultaneously.

Connecting oral and written discourse

Previous literacy research in this area has shown that students' written work typically lags behind their ability to communicate orally (Kantor & Rubin, 1981). This is seen in our work on student participation in scientific argumentation as well and is visible in examples 1 and 4, above. That their verbal argumentation can be more complex than their written suggests the importance of engaging in the argumentation as a discourse rather than focusing solely on their written products; their written products may under-represent their abilities and may not afford the students opportunities to push on their thinking.

We suggest that this gap between the students' written and verbal arguments exists for two possible reasons: 1.) students' writing skills may not be sufficient for communicating their complex argumentative thoughts and 2.) students have little reason to develop rich, convincing arguments in writing while a dialogic interaction provides students with that reason in the form of an audience to convince. Audience is important because it provides a purpose for their arguments—without an audience to convince, students are in the position to demonstrate that they understand the science but not to explicate a convincing argument. Moreover, these two goals have different success paths: to demonstrate understanding students need to have a correct claim and allude to the desired scientific concepts while constructing a convincing argument requires that students articulate evidence and reasoning (Berland & Reiser, 2009). In other words, without an argumentative audience, students have little reason to construct complete argumentative products and, as students' written work is usually written with the purpose of demonstrating understanding to the teacher, it is unsurprising that their written arguments would lack these key components. It is particularly unsurprising that student written arguments so frequently lack rebuttals—when writing arguments, students are not hearing counter-arguments that they must rebut. Ideally students will internalize the argumentative discourse and begin to construct counter-arguments themselves. However, this takes time and will not occur until after students have begun including rebuttals in spoken arguments (Wertsch, 1979).

That students' verbal and written arguments are likely to differ in complexity suggests that they may require different types of support for the two modes of communication. For example, written arguments may require more of a focus on audience while spoken arguments may benefit from a greater focus on incorporating the science concepts in students' reasoning. The details of how these supports might differ should be the focus of future studies.

Teacher instructional strategies

Finally, the teacher can influence the argumentative process by facilitating students in taking up the different discourse moves. We suggest that this works through a combination of modeling the discourse practice and prompting students to engage in particular aspects of it. This learning progression dimension of the argumentative process moves from teacher as the primary participant to teacher facilitating students in arguing with one another to students as the primary participant. Since this type of practice can be new to students, the teacher can play an essential role for moving students along the progression. Students need a model of what it looks like to evaluate or question the ideas in science class. Furthermore, a supportive environment is important to developing the norm that individual's ideas are expected to change and be revised over the course of a classroom discussion. Through the teacher's use of various instructional strategies the expectation is that these discourse moves become the norm of classroom discussions such that students spontaneously defend, evaluate, question and revise the ideas under discussion, as discussed above.

When teachers incorporate a variety of instructional strategies into their classroom practice with the same common goal of supporting students in scientific argumentation, students are also more successful in writing scientific argumentation products (McNeill, 2009). Teachers can incorporate a variety of different strategies such as defining scientific argumentation, modeling and critiquing examples, providing a rationale, connecting to everyday examples and providing students with feedback. Incorporating multiple strategies provides students with different avenues to develop an understanding of this complex practice. These strategies also need to align with the goals of the curriculum in that the teacher and curriculum work synergistically to provide students with greater support (McNeill & Krajcik, in press). Consequently, effective learning environments include the teacher and curriculum working in concert to support students in developing an in-depth understanding of argumentation over time.

Implications

As illustrated in this proposal, we view these three dimensions—problem context, argument product and argument process—as a tool for analyzing student work in the practice of scientific argumentation and for supporting students in that work. In both of these uses, it is important to recognize that the dimensions in our learning progression are not age dependent—the ways with which students engage in scientific argumentation depends more on their experience and comfort with the norms of the discourse and the content than it does on their age. In fact, we saw in the above examples that the eldest students (example 1) had some of the weakest arguments while some of the 5th grade students (example 3) were able to construct complex arguments in terms of both the product and process. Moreover, other work suggests that students have the skills to engage in scientific argumentation (Berland & Hammer, 2009; Berland & Reiser, 2009; Louca, Hammer, & Bell, 2002; Radinsky, 2008). This work emphasizes that this learning progression is not age dependent and, instead, is related to student understandings of the classroom norms—of whether and how participation in argumentative discourse is expected.

However, we do believe there are characteristics of argumentation that could be more complex for 12th graders compared to 5th graders if they were provided with the appropriate support across time. Specifically, in terms of what counts as appropriateness and sufficiency for the different components of the scientific argument. As older and more experienced students develop a stronger understanding of both the content and scientific argumentation, these aspects of their argument will become more complex and nuanced. For example, a 5th grade student could construct a scientific argument about which site has the highest biodiversity using evidence such as number and type of species, while a 12th grade student could use more complex evidence, such as the Simpson and Shannon-Weaver indices as measures of biodiversity (Begon, Harper, & Townsend, 1996), which require a stronger understanding of the content as well as mathematical manipulation of the data. In this way, the expectations of what counts as appropriate and sufficient would change. Yet in neither case does the students' age limit their ability to include some type of evidence and reasoning to support their claim.

We also acknowledge that our examples only extend down to grade 5. Students in early elementary school may struggle with some aspects of scientific argumentation, such as the reasoning component. That said, other work (Metz, 1995) suggests that younger elementary students can support claims with evidence. We therefore suspect that this learning progression would work well in younger grades, as well.

In addition, we do not expect students to work through the dimensions at similar speeds. In fact, we expect them to gradually move the product and process dimensions while they iterate on the problem context dimension in order to account for and enable content that is increasingly complex. Yet we do think the highest levels of argumentation within our progression are achievable for grade 5-12 students when provided with the appropriate support. To accomplish this, classroom communities need to create norms of interacting that align with this complex practice, thereby enabling them to refine the ways in which they participate in it.

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